Distribution of macrobenthic fauna in Phawong and U-Taphao canals flowing into a lagoonal lake, Songkhla, Thailand

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Abstract

The macrobenthic fauna of two discharge ecosystems, Phawong Canal and U-Taphao Canal flowing into Songkhla Lake in Thailand, were studied from August 1994 to August 1995. The salinity of Phawong Canal and U-Taphao Canal ranged from 0.1 to 27.8 and 0.1 to 17.0 practical salinity units (PSU), respectively. The biochemical oxygen demand (BOD) of Phawong Canal ranged from 2.5 to 33.0 $mg\,L^{-1}$, while that of U-Taphao Canal ranged from 1.1 to 12.6 $mg\,L^{-1}$. Temporal changes in the number of species and individuals were determined throughout a year. During the season of heavy rains (November–December), the density and number of most species decreased markedly. Only chironomid larvae increased and these were distributed in the uppermost reaches of the canals during this period. Sixty-two and 52 species of macrobenthic fauna were found in Phawong Canal and U-Taphao Canal, respectively; however, the abundance and number of species collected at each sampling was very low in the upper reaches of the canals. The most numerous benthic fauna in the Phawong Canal were polychaetes, followed by amphipods. Pelecypods and gastropods were the dominant groups in U-Taphao Canal. A distribution pattern of macrobenthic fauna associated with pollution gradients (BOD) was observed only at Phawong Canal. In addition, species diversity according to the Shannon-Wiener index only was not applicable to the assessment of benthic environmental health when the few individuals found were evenly distributed among the few species present at U-Taphao Canal. It is recommended that a coastal care project be established by the appropriate government agencies in the study areas.

Key words

distribution, lagoonal lake, macrobenthic fauna, salinity and BOD gradients, Thailand.

INTRODUCTION

Thale Sap Songkhla, the outer Songkhla Lake, has many rivers and streams flowing into it (Fig. 1). U-Taphao and Phawong Canals are important sub-systems of the main Songkhla Lake, when considering the composition of the total aquatic ecosystem. In recent times, both canals have been increasingly polluted by industrial discharges, especially U-Taphao Canal which flows through Hat Yai, the largest industrial centre in south Thailand (Songkhla Provincial Industrial Office, 1995). Some publications and reports have shown concern with water pollution in the study area (Rittiboon and Angsupanich 1996; Environment Laboratory for Southern Part of Thailand 1995, unpubl. data); none has been directed at determining polluted areas by benthos distribution. Benthic communities have been considered the best biological indicators of pollution in marine and estuarine environments (Wass 1967). Although studies, relating benthos and pollution have frequently been published (Rosenberg 1976; Rosenberg 1977; Pearson & Rosenberg 1978; Tamai 1982; Tsutsumi & Kikuchi 1983; Grizzle 1984; Brown *et al.* 1987; Moreira *et al.* 1993; Henderson & Ross 1995), there have been very few such studies in Thailand. Therefore, the macrobenthic fauna was studied in relation to physico-chemical characteristics. An attempt was also made to assess the horizontal distribution patterns associated with pollution gradients.

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METHODS

Sites

Phawong Canal (7°14′N, 100°34′E) and U-Taphao Canal (7°14′N, 100°28′E) are located on the Songkhla Coastal

Plain and drain into the outer Songkhla Lake (Thale Sap Songkhla, Fig. 1). Phawong Canal is about 5 km from mouth to origin. Because this canal drains industrial wastewater and runoff, it is low in dissolved oxygen (0.0–9.2 mg L^{-1}) and high in ammonium (0.0–788.4 µg-at L^{-1}), nitrate (0.24–57.75 µg-at L^{-1}), and phosphate (0.16–84.10 µg-at L^{-1}; Rittiboon & Angsupanich 1996). As a result, Phawong Canal has a high phytoplankton biomass: phytoplankton density ranges from 0.2×10^6 to 11.0×10^6 cells L^{-1}. Nutrient concentrations decrease with distance from origin (Rittiboon & Angsupanich 1996). The salinity is primarily influenced by rainfall, runoff, and tidal action. Mangrove trees were observed along the canal banks. About 14 mangrove plant species were identified near the mouth of the canal; however, in recent years the mangrove forest has decreased because of the construction of buildings in the area.

U-Taphao Canal is relatively long (about 90 km). Its origin is in the Sangala Kiri mountain range near the Malaysian border. Water from the upper reaches is used for the domestic water supply in Hat Yai. However, water from the lower reaches is affected by wastewater discharge from households and industrial factories (Environment Laboratory for Southern Part of Thailand 1995, unpubl. data). A few species of mangrove plants were found near the mouth of the canal. Only the first 15 km from the mouth of this canal were studied as this includes the ecotone area and the area of industrial pollution.

Both canals are influenced by the SW monsoon (the light rainy period, mid-May to mid-October), the NE monsoon (the heavy rainy period, mid-October to mid-February), and the dry season (mid-February to mid-May), which is very hot and has no rain (Climatology Division 1989).

Sampling and analyses

From August 1994 to August 1995, benthic grab samples were collected at six stations in each canal and two more were established in the Songkhla Lake 500 m from the mouth of each canal to be used for comparing species richness between the canals and lake. Bimonthly samplings of macrobenthic fauna were carried out in triplicate at each station using Tamura's grab (Rigosha Co., Japan, 0.05 m^2). The samples were sieved consecutively through three orders of screens of 5 mm, 1 mm, and 0.5 mm mesh; the animals were removed with forceps; and the 0.5 mm mesh screen residue was also collected. The materials were fixed in 10% rose-bengal formalin and transferred to 70% ethyl

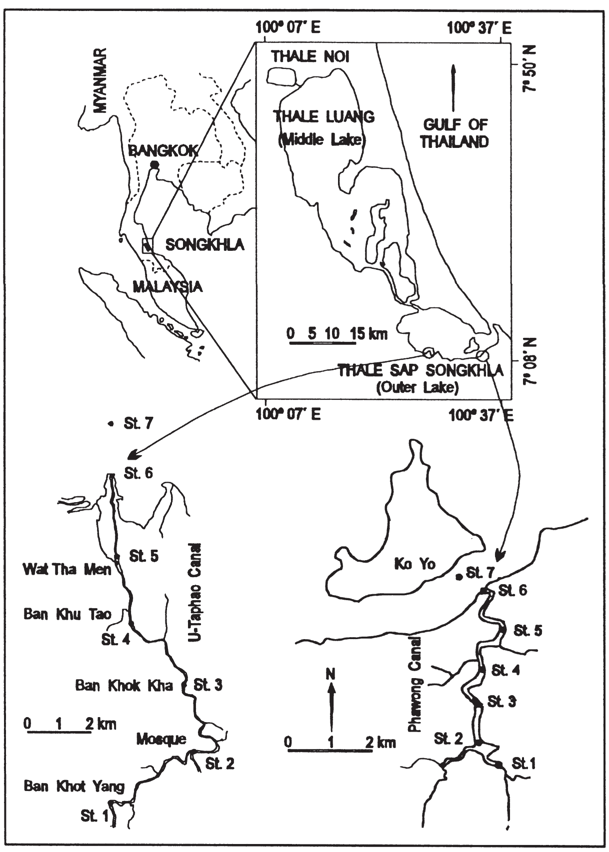

Fig. 1. Map showing Phawong Canal, U-Taphao Canal and study area.

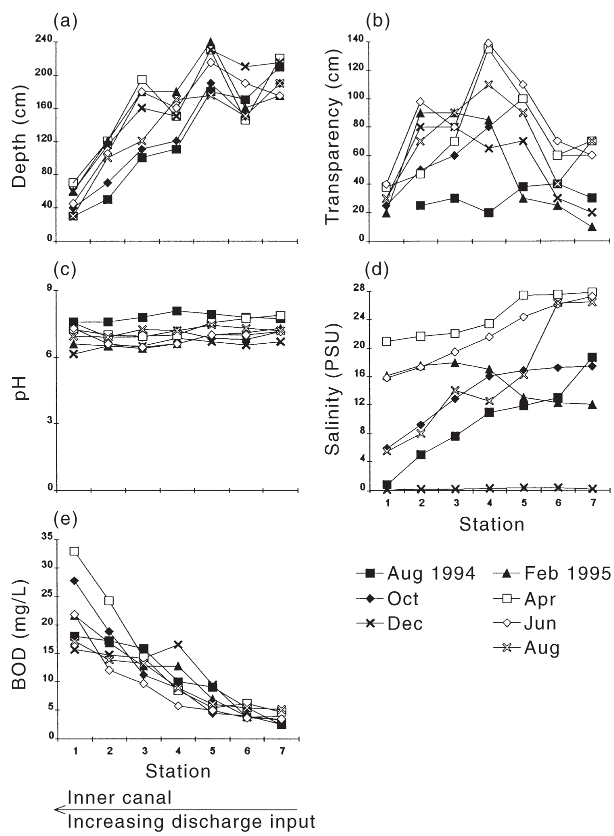

Fig. 2. Water physico-chemical characteristics of Phawong Canal. BOD, biochemical oxygen demand; PSU, practical salinity unit.

alcohol before identification. At the time of identification, individual numbers of each species were counted. Density was expressed as individuals m^{-2}. Biomasses were dry weight with shells (e.g. molluscs). Diversity of the benthic fauna was calculated using the Shannon-Wiener function, where:

$$H' = -\sum_{i=1}^{s} Pi \log_2 Pi \text{ and evenness of } H' \ (J) = H'/\log_2 s$$

At the same time as the benthic fauna samples were collected, water samples for physico-chemical analysis were collected using 1 L samplers, 50 cm from the surface of the bottom. Salinity was measured with a salinometer (Sal-50, Central Kagaku Co. Ltd., Tokyo), pH by Horiba B-111 pH meter, transparency by a Secchi disc, and biochemical oxygen demand (BOD) by the standard 5-day incubation method. Samples for sediment analyses were collected by Tamura's grab. Particle size and organic matter were determined by the hydrometer method (Gee & Bauder 1986) and the Walkley and Black method (Nelson & Sommer 1982), respectively.

RESULTS

Phawong Canal

Physico-chemical characteristics

Water depths ranged from 30 to 240 cm (Fig. 2a). The uppermost reaches (St. 1) had the shallowest area, while there was no major difference in water-levels among other stations. Secchi disc transparencies were less than 100 cm most of the year, even in the heavy rainy season (Fig. 2b).

Water pH ranged between 6.2 and 8.1 (Fig. 2c). There was no major difference in water pH in the seasonal patterns at each station, although pH tended to decrease (6.2–6.9) in the heavy rainy season (December). Salinity ranged from 0.1 to 27.8 practical salinity units (PSU; Fig. 2d). Minimum salinity (0.1–0.4 PSU) occurred in the heavy rainy season as a result of increased river flow, with peaks in salinity in the dry season (April) at high spring tides during intrusions of high salinity waters (20.9–27.8 PSU). Generally, however, the salinity at stations near the mouth of the canal was higher than those at the inner canal, which gradually decreased towards the upper reaches. BOD ranged from 2.5 to 33.0 mg L^{-1} during the study, with maximal values (17.1–33.0 mg L^{-1}) in the upper reaches and minimal (2.5–6.2 mg L^{-1}) at the stations near the mouth of the canal (Fig. 2e). The highest BOD value was found in April at St. 1. Organic matter ranged from 5.13 to 9.64% (Table 1). The highest percentage was found at St. 3.

Components of the sediments revealed a generally uniform distribution in Phawong Canal (Table 1), in which the composition of clay with silt was almost the same at every station except St. 1 and St. 7, at the lake basin in front of the river mouth where the percentage of clay abruptly decreased.

Fauna

Table 2 shows the list of species and the station at which each species was found, the abundance, station of maximum density, and the month of most abundant occurrence. Benthic fauna found in the Phawong Canal from August 1994 to August 1995 comprised five phyla and 75 species: Coelenterata (one species), Platyhelminthes (one species), Annelida (30 species), Arthropoda (26 species) and Mollusca (17 species). The major taxa were annelids (polychaetes, 28 species), arthropods (crustaceans, 24 species) and molluscs (pelecypods, 10 species and gastropods, seven species). Fifty-two species were found in the lake (St. 7), while 62 species were found in the canal (Sts 1–6). Stations showing the higher diversity of species tended to be found at the lower reaches, which is the area of relatively higher salinity (St. 1, 1 species; St. 2, nine species; St. 3, 9 species; St. 4, 21 species; St. 5, 40 species; St. 6, 33 species). Species that were most abundant were *Ceratonereis hircinicola*, *Nephtys polybranchia*, *Prionospio* sp., *Heteromastus filiformis*, *Potamilla reniformis*, *Tarebia riqueti*, *Eriopisella sechellensis*, *Idunella chilkensis*, *Grandidierella* sp., *Corophium acherusicum*, *Alpheus euphrosyne* and *Chironomus* sp. (similar to *Chironomus salinarius*). The maximum occurrence of each species in the SW monsoon period (32–37 species) was higher than in the NE monsoon period (22–23 species) and the dry season (25 species). An exception was in August 1995 when the faunal species decreased.

Table 1. Organic matter and particle size of sediments

	Station	Organic matter (%)	Particle size		
			% Clay	% Silt	% Sand
Phawong Canal	1	7.81	16.98	37.99	45.03
	2	7.22	47.15	11.98	40.87
	3	9.64	40.89	18.76	40.35
	4	7.05	46.89	15.78	37.33
	5	5.13	42.72	20.13	37.15
	6	6.23	41.29	20.51	38.20
	7	5.90	28.58	20.10	51.32
U-Taphao Canal	1	0.78	12.49	1.32	86.19
	2	2.82	44.53	15.23	40.24
	3	1.93	21.30	7.49	71.21
	4	1.10	14.13	1.15	84.72
	5	3.16	35.89	15.60	48.51
	6	3.41	44.47	19.73	35.80
	7	2.31	26.85	16.35	56.80

Table 2. List of macrobenthic fauna obtained from Phawong Canal area

Taxa	Distribution (station)	Max. density (ind m^{-2})	Occurrence 1994	Occurrence 1995
Coelenterata				
Unidentified medusa	6,**7**	33	Dec	**Jun**
Platyhelminthes				
Turbellaria	**5**	33	**Aug**	
Annelida				
Polychaeta				
Aphroditidae				
Phyllodoce sp.	**5**	7	**Aug**	
Syllidae				
Autolytus sp.	**5**	7	**Aug**	
Pilargidae				
Sigambra sp.	4,5,**6**,7	33	Aug,Oct,Dec	**Feb**,Apr,Jun
Nereidae				
Namalycastis longicirris Takahashi	3,**5**	13	**Aug**,Oct,Dec	
Gymnonereis fauveli Pillai	**5**,6,**7**	53	**Aug**,Oct,Dec	**Jun**,Aug
Neanthes sp.	**6**,7	20	**Aug**	
Ceratonereis hircinicola Eisig	4,**5**,6,7	740	**Aug**,Oct,Dec	Feb,Apr,Jun,Aug
Nephtyidae				
Nephtys polybranchia Southern	4,**5**,6,7	400	Aug,Oct,Dec	Feb,Apr,**Jun**,Aug
Nephtys paradoxa Malmgren	**5**,7	53	Aug,Oct,Dec	**Feb**
Glyceridae				
Glycera sp.	6,**7**	60	**Oct**	Aug
Eunicidae				
Marphysa sanguinea Montagu	**5**,**6**,**7**	*13	**Aug**	**Aug**
Diopatra neapolitana Delle Chiaje	**7**	13		**Aug**
Lumbrineris brevicirra Schmarda	4,5,**7**	13	**Aug**	Apr,Jun,**Aug**
Orbiniidae				
Haploscoloplos sp.	**5**	7	**Aug**	
Spionidae				
Prionospio cirrifera Wiren	4,5,6,**7**	53	Oct,Dec	**Aug**
Prionospio sp.	4,5,**6**,7	480	Aug,**Oct**	Feb,Apr,Jun,Aug
Polydora ciliata Johnston	**2**,4,6,**7**	*13	Aug,Oct,Dec	**Jun**,**Aug**
Cirratulidae				
Cirriformia tentaculata Montagu	**5**,7	27	**Aug**,Oct	
Paraonidae				
Paraonis sp.	**5**,6,7	40	Oct	**Feb**,Apr,Jun
Aonides oxycephala Sars	**7**	*7		**Jun**,**Aug**
Capitellidae				
Heteromastus filiformis Claparede	5,**6**,7	333	Aug,Oct,Dec	Feb,Apr,**Jun**,Aug
Capitella capitata Fabricius	2,**4**,5,7	113	**Aug**,Dec	Feb,Apr,Jun
Sternaspidae				
Sternaspis scutata Renier	**6**	*7		**Jun**,**Aug**
Sabellidae				
Jasmineira sp.	**7**	7		**Jun**
Potamilla reniformis Müller	4,**5**,6,7	373	Oct,Dec	Apr,**Jun**,Aug
Potamilla sp.	**5**,6	53	**Aug**	

Table 2. continued

Taxa	Distribution (station)	Max. density (ind m^{-2})	Occurrence 1994	Occurrence 1995
Cossuridae				
Cossura coasta Kitamori	**6**	20		Feb,**Aug**
Maldanidae				
Euclymene sp.	**7**	*7		**Feb**,**Aug**
Oligochaeta				
Tubificidae	2,3,**4**,5,6,7	180	Aug,Oct,**Dec**	
Unidentified sp.	3,4,**5**,6,7	40		**Feb**,Apr,Jun
Mollusca				
Gastropoda				
Marginella sp.	**7**	7	**Oct**	
Cerithideopsilla angulata Gmelin	**2**	20	**Aug**	
Tarebia granifera obliquigranosa Smith	**3**	7		**Jun**
Tarebia riqueti Smith	3,**4**,5	760	Dec	Feb,Apr,**Jun**,Aug
Sinotaia quadrata histrica Gould	**6**	13		**Apr**
Stenothyra sp.	**2**,3,4	100		**Jun**,Aug
Semisulcospira sp.	**2**	7		**Jun**
Pelecypoda				
Unidentified larva	**5**,6,7	60	Aug,Dec	**Feb**
Solen brevis Gray	5,**7**	20	**Oct**	Jun
Bathytormus foveolatus Sowerby	**2**	47	**Aug**	
Perna viridis Linnaeus	**2**,3	87	**Aug**	
Eamesiella corrugata Deshayes	**7**	40	**Aug**	Jun
Potamocorbula sp.	**3**,6,7	133	Aug,Dec	**Apr**,Jun
Eucrassatella sp.	**5**	7		**Feb**
Laternula sp.	**7**	7		**Feb**
Bonartemis sp.	**7**	7		**Jun**
Unidentified sp.	**6**	40	**Oct**	
Arthropoda				
Crustacea				
Tanaidacea				
Apseudes sp.1	5,6,**7**	60		**Feb**,Apr
Apseudes sp.2	**5**	7	**Oct**	**Feb**
Isopoda				
Apanthura africana Barnard	5,**7**	27	**Aug**,**Oct**	**Apr**,Jun
Cirolana sp.	**7**	40		**Apr**
Amphipoda				
Eriopisella sechellensis Chevreux	4,**5**,6,7	387	**Aug**,Oct,Dec	Feb,Apr,Jun,Aug
Photis sp.	4,**7**	73	Aug,**Oct**,Dec	
Idunella chilkensis Chevreux	4,5,**6**,7	387	**Aug**,Oct,Dec	Feb,Apr,Jun,Aug
Ericthonius brasiliensis Dana	4,**5**	13	**Aug**	
Grandidierella sp.	4,5,6,**7**	893	Aug,Oct	**Feb**,Apr,Jun,Aug
Corophium acherusicum Costa	**5**,6,7	287	**Aug**,Dec	Apr
Maera sp.	**7**	7	**Aug**	
Liljeborgiidae	6,**7**	13	Oct	**Apr**
Phoxocephalidae	5,**7**	33		Apr,**Jun**,Aug
Mysidacea	**7**	13	**Oct**	

Table 2. continued

Taxa	Distribution (station)	Max. density (ind m^{-2})	Occurrence 1994	Occurrence 1995
Harpacticoida (Copepoda)	**5**,7	27	Oct	Feb,**Apr**,Aug
Upogebia sp.	5,6,**7**	227	**Oct**,Dec	
Crab	**7**	7		**Jun**
Lucifer sp.	**5**,**7**	*7	**Oct**	**Aug**
Alpheus euphrosyne de Man	6,**7**	1180		**Feb**,Apr,Jun,Aug
Alpheus malabaricus songkla subspecies nov.	**7**	33		**Feb**
Alpheus rapax Fabricius	**5**	7		**June**
Metapeneus ensis de Haan	6,**7**	20	Oct,Dec	Feb,**Jun**
Cumacea				
Iphinoe sp.	4,**7**	13	**Aug**,Oct	Aug
Bodotria sp.	6,**7**	93	**Aug**	
Insecta				
Chironomus sp. (*C. salinarius*?)	1,**2**,3,4,5	633	Aug,Oct, Dec	Apr,**Jun**
Hemiptera larva	**4**	7	**Dec**	

Data shown relate to distribution (station), maximum densities and monthly occurrence. Bold indicates station and month of maximum density. *Indicates the same density.

The percentage of main benthos groups at each station, the sampling times and the total individual numbers per square metre are shown in Fig. 3. Sts 1 and 2 were primarily occupied by a chironomid insect larva in August and December 1994 and June 1995; occasionally this extended to St. 4 in the lower reaches. Polychaetes occupied only St. 4 and downwards, and showed higher percentages at Sts 5 and 6 and occasionally at St. 7, which indicated that these brackish water zones are suitable for polychaetes. The molluscan group, Gastropoda and Pelecypoda, mostly occupied the middle zone of the river (Sts 2–4), with a moderate range of individual numbers at numerous sampling times. *Tarebia riqueti* was the dominant species. Additionally, crustaceans were mainly distributed in stations at the lower reaches and St. 7 at the lake in front of the river mouth. Most crustaceans found in these areas were amphipods (Table 2).

Figure 4 shows the summarized characteristics by species diversity and evenness, number of species and by individuals m^2 and biomass, which have similar gradients from the lowest values at St. 1 and the uppermost points to the highest values at the lake, indicating an abundance of benthic fauna. The biomass (g m^2) only shows a prominent peak at St. 4 located at the middle zone of the rivers, due to the abundance of the gastropod *T. riqueti*. Other benthic species were mostly of a smaller size and were not significant in increasing the biomass.

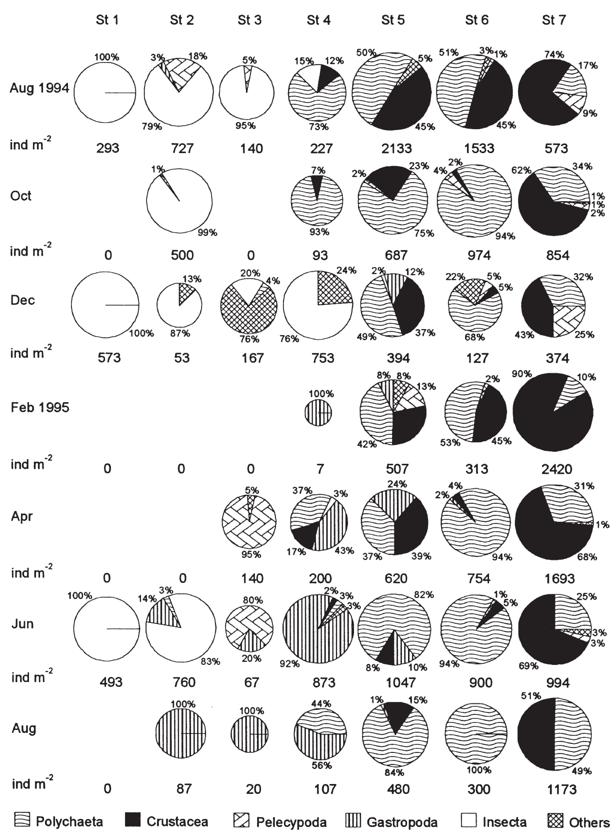

Fig. 3. Percentages of macrobenthic fauna groups obtained from Phawong Canal. Circled areas expressed as mean individuals m^{-2} in a logarithmic value. (Others = Medusa + Turbellaria + Oligochaeta.)

U-Taphao Canal

Physico-chemical characteristics

Water depths (Fig. 5a) were highly variable (85–590 cm) during the study period. Water depth in Thale Sap Songkhla was less than in the canal. Water clarity (Fig. 5b) was always low (<100 cm Secchi disc depth), particularly from August to October when it was often as low as 10 cm.

The pH ranged between 5.8 and 7.7 (Fig. 5c). The values were rather low in December (5.8–6.0). Salinity ranged from 0.1 to 17.0 PSU. Intrusion of highly saline waters resulted in salinity gradients, which were most marked in the dry season (February–April) to the beginning of the SW monsoon (June) (Fig. 5d). For the rest of the year, however, the upper reaches of the canal were dominated by freshwater flows. The BOD of the canal water ranged from 1.1 to 12.6 mg L^{-1}, with a large increase occurring in February

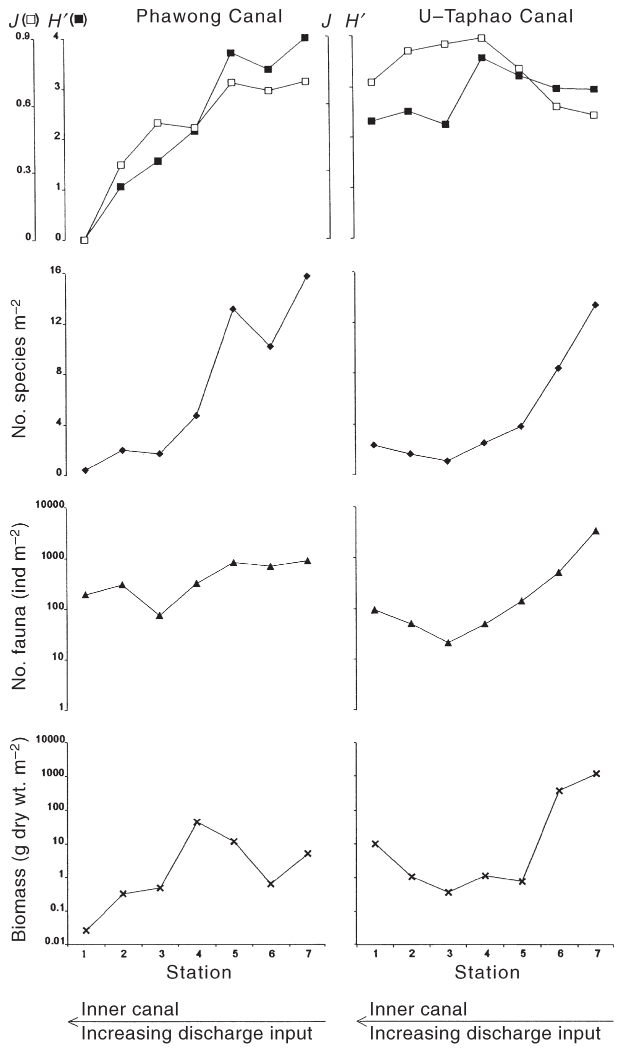

Fig. 4. The overall mean values of *H′*, *J*, number of fauna, number of species, and biomass for the seven stations over the period of the study.

(Fig. 5e). There was no marked difference in BOD among stations. Organic matter ranged from 0.78 to 3.41% (Table 1). Station 6 had the highest values.

The composition of sediment showed a different pattern from that of Phawong Canal (Table 1). Some stations in the canal (Sts 1, 3 and 4) contained high percentages of sand (71.21–86.19%) and low percentages of silt (1.15–7.49%). This may relate to the low organic matter (0.78–1.93%) which occurred in the stations mentioned.

Fauna

Table 3 shows the list of species in U-Taphao Canal, with indications of the stations where each species was found, the abundance, station of maximum density, and month of most abundant occurrence. A total of four phyla and 67 species were identified. There were Porifera (one species), Annelida (26 species), Mollusca (21 species), and Arthropoda (15 species). The major taxa were annelids (polychaetes 22 species), arthropods (crustaceans 15 species) and molluscs (pelecypods 13 species and gastropods eight species). Cyclophorid shells were found, but without live animals, precise identification was not possible. Forty-three species were found in the lake (St. 7), while 52 species were found in the canal (Sts 1–6). Thirty-three species were also

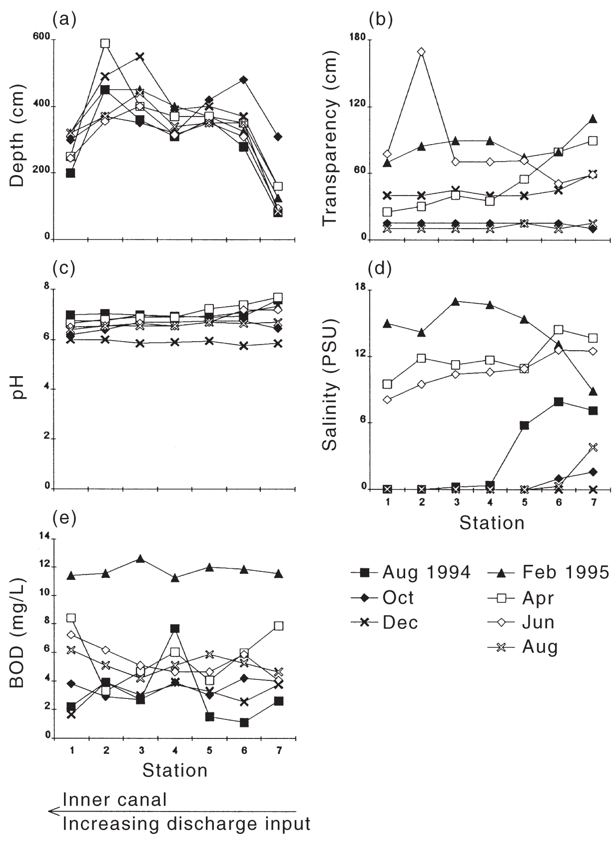

Fig. 5. Water physico-chemical characteristics of U-Taphao Canal. BOD, biochemical oxygen demand; PSU, practical salinity unit.

Table 3. List of macrobenthic fauna obtained from U-Taphao Canal area

Taxa	Distribution (station)	Max. density (ind m^{-2})	Occurrence 1994	Occurrence 1995
Porifera				
Unidentified sp.	**2**	13		**Aug**
Annelida				
Archiannelida				
Unidentified sp.	**1**,4	53		**Apr**,Aug
Polychaeta				
Pilargidae				
Sigambra sp.	**7**	20		**Feb**,Jun
Nereidae				
Namalycastis longicirris Takahashi	3,4,**5**,6,7	93	Aug,Oct,**Dec**	Feb,Apr,Jun
Gymnonereis fauveli Pillai	4,6,**7**	60	**Aug**,Oct	Aug
Neanthes sp.	**7**	20	**Aug**	
Ceratonereis hircinicola Eisig	6,**7**	1313	Aug,Oct	Feb,Apr,**Jun**
Nephtyidae				
Nephtys polybranchia Southern	5,**6**,7	353	Aug,**Oct**,Dec	Feb,Apr,Jun,Aug
Nephtys paradoxa Malmgren	**6**	20		**Feb**,Apr
Glyceridae				
Glycera sp.	**7**	7		**Aug**
Spionidae				
Prionospio cirrifera Wiren	4,6,**7**	107		**Aug**
Prionospio sp.	**4**,**5**	*7		**Aug**
Polydora ciliata Johnston	6,**7**	487	Aug	**Feb**,Apr,Aug
Unidentified sp.	**6**	7	**Aug**	
Cirratulidae				
Cirriformia tentaculata Montagu	6,**7**	100	Aug,Oct	**Feb**,Apr,Jun,Aug
Paraonidae				
Paraonis sp.	**6**	13		**Aug**
Capitellidae				
Heteromastus filiformis Claparede	6,**7**	747	Aug,Oct	Feb,Apr,**Jun**,Aug
Capitella capitata Fabricius	**6**,7	640	Oct,**Dec**	Aug
Eunicidae				
Nematonereis unicornis Grube	**7**	7	**Aug**	
Marphysa sanguinea Montagu	**6**,**7**	*7		**Apr**
Lysidice collaris Grube	**7**	33		**Apr**,Aug
Orbiniidae				
Naineris laevigata Grube	6,**7**	13		**Aug**
Opheliidae				
Armandia longicaudata Caullery	**7**	13		**Aug**
Sabellidae				
Potamilla reniformis Müller	**7**	27		Jun,**Aug**
Oligochaeta				
Tubificidae	**1**,2,3,4,5,6,7	247	Aug,Oct,**Dec**	
Unidentified sp.	**6**,7	53		**Feb**
Hirudinea	**1**	7		**Aug**
Mollusca				
Gastropoda				
Marginella sp.	6,**7**	173	Aug,Oct	Feb,**Apr**,Jun
Stenothyra sp.	**2**,4,5,7	87	Aug,Oct,**Dec**	Aug

Table 3. continued

Taxa	Distribution (station)	Max. density (ind m^{-2})	Occurrence 1994	Occurrence 1995
Tarebia granifera obliquigranosa Smith	4,5,6,**7**	2207	Aug,Dec	Feb,**Apr**,Jun,Aug
Tarebia riqueti Smith	**4**,7	47		Jun,**Aug**
Neritina gagates Lamarck	1	7	**Dec**	
Semisulcospira sp.	**5**	7		**Aug**
Thiariidae	**7**	40	**Dec**	
Cyclophoridae (only shells)	**2**	13	**Dec**	
Pelecypoda				
Bivalvia larva	5,**7**	20	Oct	Jun,**Aug**
Corbicula arata Sowerby	1,2,3,4,5,**7**	333	**Aug**,Oct,Dec	Apr,Jun
Corbicula baudoni Morlet	1,**5**	20	**Dec**	Aug
Corbicula noetlingi Martens	**5**	27	**Dec**	
Corbicula blandiana Prime	**3**	7		**Aug**
Hiatella sp.	1,2,3,4,**5**,6,7	193	Aug,Oct	**Jun**,Aug
Limnoperna sp.	**5**	7	**Aug**	
Potamocorbula sp.	4,5,6,**7**	6093	Aug,Oct,Dec	Feb,**Apr**,Aug
Perna virides Linnaeus	5,**7**	753	**Aug**	Aug
Eucrassatella sp.	**6**	13		**Feb**
Musculista senhausia Benson	**7**	7		**Aug**
Eolepton sp.	**6**	7		**Aug**
Mya sp.	**7**	7		**Aug**
Arthropoda				
Crustacea				
Tanaidacea				
Apseudes sp.1	6,**7**	40	Aug	Feb,Apr,**Jun**
Isopoda				
Apanthura africana Barnard	**7**	7		**Aug**
Amphipoda				
Eriopisella sechellensis Chevreux	6,**7**	467	Oct,Dec	Feb,Apr,Jun,**Aug**
Photis sp.	**6**	7	**Aug**	
Idunella chilkensis Chevreux	6,**7**	180	Aug	Apr,Jun,**Aug**
Leucothoe sp.	**6**,**7**	*7	**Aug**	
Grandidierella sp.	**7**	693		**Apr**,Jun,Aug
Corophium acherusicum Costa	**7**	140		**Apr**
Unidentified Amphipoda	**7**	73	**Aug**	
Liljeborgiidae	**6**	7		**Apr**
Mysidacea	**2**,**5**	*7		**Aug**
Harpacticoida (Copepoda)	6,**7**	40		Apr,Jun,**Aug**
Crab	**7**	7		**Apr**
Metapenaeus ensis de Haan	**6**	7	**Dec**	
Alpheus euphrosyne de Man	4,**7**	53		Feb,**Aug**
Insecta				
Chironomus sp.	**1**,2,3,4,5,6	80	Aug,Oct,**Dec**	
Odonata sp.	**4**	7	**Oct**	
Hemiptera larva	1,**4**	13	**Dec**	Aug
Ephemeroptera larva	**1**,5,6	13	**Dec**	

Data shown relate to distribution (station), maximum densities and monthly occurrence. Bold indicates station and month of maximum density. *Indicates the same density.

found in Phawong Canal (Sts 1–6). Stations showing a high abundance of species tended to be found at the lower reaches of the canal (St. 1, 10 species; St. 2, eight species; St. 3, six species; St. 4, 16 species; St. 5, 18 species; St. 6, 32 species). Species showing high densities (*C. hircinicola*, *N. polybranchia*, *H. filiformis*, *Polydora ciliata*, *Capitella capitata*, *Tarebia granifera obliquigranosa*, *Corbicula arata*, *Potamocorbula* sp., *Perna viridis E. sechellensis*, and *Grandidierella* sp.) ranged between 333 and 6093 ind. m^{-2}. The highest density was obtained in a bivalve, *Potamocorbula* sp., which builds colonies and obtains suspended organic matter or detritus for food by filtration. The overall number of species slightly decreased during the NE monsoon period, although mollusc species tended to increase during this time. Figure 6 shows the percentage of the main benthos groups at each station at every sampling period, in which a high abundance of the total individual numbers at a station is mostly found at Sts 6 and 7. Low abundance was found at stations of the middle zone and occasionally at those of the upper reaches. Note that high percentages of Pelecypoda were prominent at several stations and samplings. The distribution of Polychaeta, mainly from Sts 4–7, showed high composition rates during the SW monsoon period. High percentages of the crustacean group were seen during February and August 1995 at Sts 6 and 7. However, crustaceans were not the major fauna in U-Taphao Canal.

The summarized characteristics by species diversity and evenness, number of species, numerical density, and biomass of U-Taphao Canal are shown in Fig. 4. The latter three features showed similar patterns of abrupt increases from stations at the upper reaches towards St. 7 in the lake. The reproductive zone for the canal should be assigned to the lower reaches between St. 4 and St. 7, but the indices H' and J showed opposite patterns.

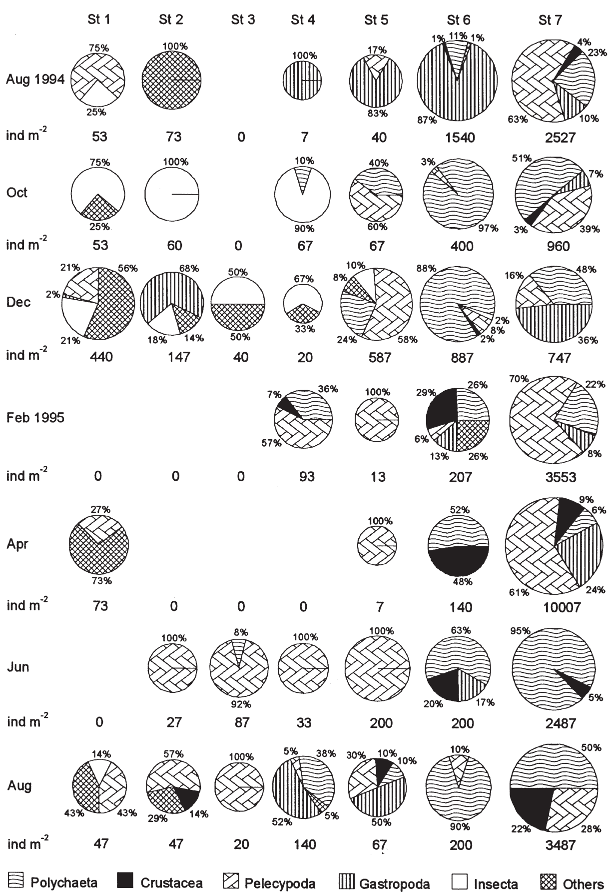

Fig. 6. Percentages of macrobenthic fauna groups obtained from U-Taphao Canal. Circled areas expressed as mean individuals m^{-2} in a logarithmic value. (Others = Porifera + Archiannelida + Oligochaeta.)

DISCUSSION

Distribution pattern associated with pollution gradient

The areas selected for this study belong to 'secondary estuarine waters' due to the inner location of Thale Sap Songkhla in which the 'primary estuary' is the mouth area of the lake which is open to the Lower Gulf of Thailand, where salinity gradients, a main component of estuarine environments, can be observed at a consistently higher range than in inner secondary estuaries such as the present study areas of the two canals.

Variations in species occurrence and changes due to environmental conditions were generally obvious at all sampling times, but seasonal changes were too complex to show specific patterns of the community gradations of each canal. However, due to particular environmental gradients, mainly BOD and salinity, prominent zones including stations adjacent to each other could be observed in Phawong Canal, as with the high abundance of *Chironomus* sp. at Sts 1 and 2 with less species diversity. This seemed to show an 'ecotone point' (a transitional zone of community gradient) as described by Pearson & Rosenberg 1978), who summarized the changes in numbers of species, abundance, and biomass of macrobenthic fauna in relation to organic pollution of temperate coastal waters. The vicinity of the waste discharge point in their study showed the least macrobenthic fauna, with the number of species gradually increasing further away from the most organically polluted area, and a more marked increase occurring after passing the ecotone point. On the heavily polluted side of this point, the community was composed of a few pollution-tolerant opportunistic species. Therefore, the 'ecotone point' as described by them is realized only in a portion of the adjacent sites, which means establishment can only be recognized in cases showing a degradation of community abundance in a diagram of enrichment inclination. This phenomenon was observed only in Phawong Canal. The number of species and abundance markedly increased from St. 5 to the outer reaches of the canal (St. 7). The mangrove assemblages distributed in the area (Meepol pers. comm., 1995) supported the food sources for benthic fauna (Angsupanich & Aksornkoae 1994). The slight decrease of species numbers and abundance of the fauna at St. 6 (the mouth of the canal) may be accounted for by occasional dredging.

The distribution pattern of macrobenthic fauna in U-Taphao Canal showed similarities to that in Phawong Canal. This may not support Pearson & Rosenberg conclusion (1978), because BOD values and organic content among stations were almost at the same levels. Moreover, the lower reaches contained higher levels of organic content. These levels, however, were lower than the lowest level found at St. 4 of Phawong Canal. Therefore, high organic pollution stress has not occurred in the area. This can be assumed from the moderate BOD values of U-Taphao Canal. The low macrobenthic fauna population in the canal may be caused by other factors. The salinity in U-Taphao Canal was low most of the year in the upper reaches, largely due to the freshwater flow from Sangala Kiri mountain. Macrobenthic fauna, therefore, were not highly abundant (this is the usual situation; Ristich *et al.* 1977; Lim *et al.* 1991; van Nes & Smit 1993) with the exception of stations close to Thale Sap Songkhla (Sts 6, 7) where there is brackish water. Most fauna found at St. 6 were the same as those found at Thale Sap Songkhla (Angsupanich & Kuwabara 1995). Within the canal, the estuarine macrobenthic species showed the lowest density, although salinity was brackish during the dry season. This indicates that a short period of brackish water conditions in the dry season cannot induce colonization of estuarine macrobenthic fauna in U-Taphao Canal. Moreover, the rather low organic matter and silt-clay fraction may inhibit colonization of macrobenthic fauna such as polychaetes, which have shown a positive correlation to certain silt-clay composition (Hylleberg & Nateewathana 1984).

Wet and dry seasons

Macrobenthic fauna in both canals were similar to that of some other estuaries in relation to decreased populations in the rainy season (Rao & Sarma 1980; van Nes & Smit 1993; Angsupanich & Kuwabara 1995). A decrease in the numbers of individuals and species at the upper reaches of the Hudson River was associated with low salinity (Ristich *et al.* 1977); however, this may not be a major factor for the upper reaches of Phawong Canal because, in general, the salinity ranged from 4.5 to 20.9 PSU with the lowest salinity (< 1) only in the heavy rainy season in December and the numbers of individuals and species relatively low all year round. This range can be tolerated by *H. filiformis* (Hartmann-Schröder 1971), which has been collected in Thale Sap Songkhla throughout the year (Angsupanich & Kuwabara 1995), even when average salinity of the water was < 5 PSU (Angsupanich & Rakkheaw 1997). Moreover, 8–13 species of macrobenthic fauna were found at Sts 6 and 7 at the mouth of U-Taphao Canal where the salinity ranged from 0.1 to 14.5 PSU. Therefore, the very low density and number of species of macrobenthic fauna at Sts 1–3 of Phawong Canal may be caused by the combination of reduced salinity and high BOD values. Separation of the relative effects of these two factors, which frequently occur in estuaries, is often difficult (Pearson & Rosenberg 1978).

Probably due to the great influx of freshwater in the rainy season, freshwater species (e.g. *Chironomus* larva, Tubificidae) of benthic fauna were found in both Phawong and U-Taphao Canals during that period and were abundant groups in this season. Chironomids have been used as indicator organisms for trophic characterization of lakes (e.g. Gerstmeier 1989). Many *Chironomus* species tolerate low oxygen water conditions, with physiological and behavioural adaptations (Pinder 1986). Their species-specific variation in response to declining oxygen levels has been related to the oxygen condition in their special habitats and to their different resistance anoxia (Bairlein 1989). The biomass of *Chironomus* was high on freshly flooded land, for instance in new lowland reservoirs and ponds (Kajak 1988). However, *Chironomus* larvae found in Phawong Canal were able to tolerate poorly oxygenated oligohaline water conditions (species not identified but with taxonomic characteristics similar to *C. salinarius*, Hashimoto 1985), which has been found in Goro Lagoon, Italy (Barbanti *et al.* 1992)). In addition, several predominant estuarine species found in Phawong Canal and U-Taphao Canal have been reported to be distributed in both temperate and tropical estuaries (Fauchald 1977). Some tolerate polluted or low oxygen waters such as *H. filiformis* (Pals & Pauptit 1979; Rosenberg *et al.* 1992), *C. capitata* (Rosenberg 1972; Ajao & Fagade 1990) and *P. ciliata* (Rosenberg 1977). In the present study, however, most of those species were found to be distributed in about half of the length of the canals, generally in the lower reaches. A small number of *P. cirrifera* and *C. capitata* were found up to St. 2 of Phawong Canal where the BOD values of water were high (12.0–24.3 mg L^{-1}).

Numerical density

Although Phawong Canal (Sts 1–6) is only short, the faunal numerical density of each sampling station varied markedly (0–2133 ind. m^{-2}). The abundance of benthic fauna at Sts 5 and 6, which are close to the mangrove community, was similar to that at Thale Sap Songkhla (Angsupanich & Kuwabara 1995) and at the mangrove area at Ban Don Bay, south Thailand (Angsupanich & Aksornkoae 1996). However, the species composition of the latter was less than that of the present study.

The faunal numerical density of each sampling station in U-Taphao Canal was also found to have variations. However, average densities were lower than in Phawong Canal. Higher occurrences of numerical densities (2487–10007 ind. m^{-2}) in U-Taphao Canal were mostly found at St. 7, the lake area. Molluscs (e.g. *Potamocorbula* sp., *T. granifera obliquigranosa*, and *C. arata*) were the major components. Therefore, macrobenthic fauna would not seem to provide an important food source to demersal fish and large invertebrate predators within U-Taphao Canal.

Species diversity indices

In Phawong Canal, the ranging of stations along a gradient of organic pollution was obvious using the changes of species composition and density throughout the year as well as the values of H' and J, unlike U-Taphao Canal, where confusing results from these indices were found. For example, in U-Taphao Canal, the H'-value of St. 7 (2.91) was lower than that in St. 4 (3.55), although the number of species at St. 7 was much higher (Fig. 4). This was due to the much higher J value (lower dominance of component species) found in St. 4 (e.g. Hawthorne & Dauer 1983). Moreover, in a comparison of community structures between these two canals, it is again difficult to conclude which canal is more polluted. Diversity indices have been widely used to characterize benthic communities in different regions of the world. A number of studies have dealt with benthic faunal dynamics (Rosenberg 1976; Rosenberg 1977) and the environmental impact of pollution (Wu 1982; Brown *et al.* 1987; Henderson & Ross 1995). Some of the disadvantages of these indices have already been discussed. The use of these diversity indices must be done with great care because they are not completely reliable as an assessment of benthic environmental health (Rosenberg 1976; Rosenberg 1977). Species diversity measures have been suggested to be poor indicators of pollution, with changes in species composition and density over time being better indicators (Smith *et al.* 1979 cited in Hawthorne & Dauer 1983).

Given the importance of these canals in providing domestic water supplies to a large number of people in the Songkhla Lake area, and also the importance of the inflow of non-polluted water into Songkhla Lake in maintaining the health of this national resource, it is highly recommended that the appropriate government agencies undertake further study in this area, with particular emphasis on the needs of the coastal areas for soil conservation, maintenance of biodiversity, revegetation, management of urbanization and associated activities, and continued monitoring of the canal's environment.

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